LATEST DANISH MAP OF REGION NORTH OF UPERNIVIK

C, Cornell glacier; S, Mount Schurman

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FORMER EXTENSION OF CORNELL GLACIER NEAR THE SOUTHERN END OF MELVILLE BAY*

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(*Read before the Society December 30, 1896*)

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MEANING OF RUGGED TOPOGRAPHY ON THE GREENLAND COAST.

VIEWS HELD.

From the earlier belief that the Greenland and American ice-sheets were united during the Glacial period there has of late been a reaction, and the pendulum has swung so far in the opposite direction that it is now said that the Greenland glacier has probably never extended so far beyond its present margin, but that many of the peaks of the islands and

*In making this study I am greatly indebted to all of my colleagues of the Cornell party, which besides myself was composed of the following: Professor A. C. Gill and Messrs J. A. Bonsteel, T. L. Watson, J. O. Martin, and E. M. Kindle. Each one rendered me much aid in obtaining facts, making suggestions, and in discussing conclusions. I wish also to express my indebtedness to Lieutenant Peary for the opportunity to make the study, as well as for the admirable way in which he carried out the plans which he laid before me. Above all, the party is indebted to Mr E. G. Wyckoff, of Ithaca, New York, who furnished the money for the expedition, without which the investigations would not have been possible.

peninsulas bounding the Greenland insular land mass escaped glaciation. This opinion has been expressed by both Professors Chamberlin and Salisbury as a result of their recent studies upon the Greenland coast.*

My conclusions, based on a study of a part of the Greenland coast in 1896, are of a directly opposite nature. All the land studied in any detail by the Cornell party was found to have been glaciated, and we saw no reason for believing that glaciers had not covered all the land and reached beyond it out to sea. Direct evidence of markedly greater ice extension was found on the Upper Nugsuak peninsula in latitude 74° 10′–15′. It is a statement of the conditions in this locality that this paper is chiefly intended to give.

CONSIDERATION OF THE EVIDENCE OPPOSING GENERAL GLACIATION.

As has been said, the Cornell party found no evidence opposing the theory of general glaciation; but both Chamberlin and Salisbury have put forward evidence of this nature. This is of two kinds: One the presence of a driftless area in the Inglefield Gulf region, announced by Professor Chamberlin, and a second the angular topography of part of the Greenland coast, described by both. The first I do not propose to discuss.†

The second evidence is that, although some of the land is noticeably rounded, other parts, and usually the higher areas, are angular. Distinctly angular peaks are said to rise above well polished and rounded valley bottoms and low hillsides. These facts are strikingly shown all along the Greenland coast, and in this respect I can agree to the observations; but my interpretation of them is quite different from that of Chamberlin and Salisbury. In this difference of topography I have found evidence that the ice had more work to do on the higher peaks, less ability to perform the work, and less time in which to do it than in the valley bottoms. Since it is diametrically opposed to the current belief, this interpretation needs amplification.

Other things being equal, a high peak is more rugged than the lower hills, because the action of the agents of denudation is more powerful. This applies to both preglacial and postglacial conditions; conse-

*See particularly Chamberlin: Jour. Geol., vol. ii, 1894, p. 652, and Bull. Geol. Soc. Am., vol. vi, 1894, p. 219; and Salisbury: Jour. Geol., vol. iii, 1895, p. 875, and vol. iv, 1896, p. 769.

Since the above was written there has been a discussion upon this point, commenced by Professor Chamberlin, Jour. Geol., vol. v, 1897, p. 81, and continued in Science, 1897, pp. 344, 400, and later numbers.

† I would hardly be warranted in discussing the evidence from a region that I have never seen; yet I cannot let this opportunity pass without raising the query whether the topography in the neighborhood of the Greenland driftless area is not such that an area of this sort would naturally be expected. Was not the movement of the ice outward and the main stream down the Inglefield gulf? And is not the driftless area located in the place where the high Red Cliff peninsula might naturally have clogged the ice and hence prevented its action of erosion and notable transportation?

quently it may be expected that peaks rising two or three thousand feet above the valley bottoms were more rugged before the ice came and have been more denuded since the ice left than has been the neighboring lowland. That the latter is true is abundantly proved on every hand. High areas bearing glacially transported materials have been attacked by the frost and gullied extensively by the action of the snow water of spring,* while the rocks of the lowland are still distinct *roches moutonnées* forms, sometimes still grooved and polished.

The high peak rising above the valley, especially if this is broad, is not so readily worn by the glacier as the lower land. This is due partly to the fact that the ice-currents, deflected by the land topography, are more powerful and persistent in the valleys. That this is true is perfectly apparent, and we may see proof of it on the surface of the present glaciers of Greenland. In the valleys the ice projects beyond the average margin, entering the sea and there floating away in the form of icebergs. There is evidence of rapid movement in these valley portions and very slight motion over the ridges and peaks. The divide between two valley glaciers near the margin of the ice-cap is usually smooth and relatively unbroken, while the valley portion is intricately crevassed; but even over these divides there is some movement, as is shown by the stratification at the base of the land margin and by the debris in the ice.

Not only is there less rapidity of movement, but the peaks rising into the ice reach above the level of the debris zone, and thus have a relatively slight attack upon them. As this ice is mainly clear and moraine-free, the destruction must be mainly done by the ice itself, not by tools held in its grasp.

Granting for the moment that all the land was ice-covered, and that the present margin of the glacier is only one stage in the general retreat, there must have been a time when the peaks rose above the ice as nunataks, while the valleys were still occupied by glaciers. This condition must have lasted for a long time, and the same was true when the glacier began to encroach upon the land. First the valleys were occupied, then the hilltops were enwrapped, and finally all land was buried beneath the advancing ice-cap; hence the valleys were actually occupied very much longer than the mountains, and this necessitates not only a difference in ice erosion, but also a much greater preglacial and postglacial exposure to denudation for the mountain tops than for the valley bottoms.

For these reasons we may naturally expect the topography of the higher peaks to be very much more angular than that of the lower land, and there would be a marked difference in the ruggedness of peaks, according to even slight variations in rock structure and position as well

* See Tarr: American Geologist, vol. xix, 1897, p. 131.

as in land elevation. Moreover, there would be a variation according to the point of view. Seen from a vessel at sea, the peak will naturally be more angular than when viewed from the land side, which is the direction from which the ice moved, and hence in which the ice erosion was greatest. This difference in ruggedness would decrease as the time of ice action increased; therefore marked ruggedness may possibly be considered as an evidence that the ice covered the high land only for a brief period through this seems by no means certain, since there is little opportunity for ice erosion on the high points.

Instance of glaciated rugged Topography.

On the Upper Nugsuak peninsula (see plate 25), where the Cornell party spent a month, there was a chance to test the validity of this interpretation. The Devil's Thumb * rises about 2,650 feet above the sea-level and presents a seaward face of rugged outline (plate 26). Transported pebbles were found on its top. At the end of the Upper Nugsuak peninsula Wilcox Head rises 1,400 feet above the sea as a rugged and serrated peak, and upon it are patches of boulder-clay and innumerable transported blocks. Numerous other points on the peninsula reach to elevations between 1,000 and 2,600 feet. These higher peaks are very angular, but upon the tops of all of them that were ascended numerous transported fragments were found. On the crest of the nunatak named mount Schurman, about seven miles from the margin of the ice-sheet, transported pebbles were obtained at an elevation of 2,210 feet above the sea and 1,000 feet above the ice-surface at the western base of the mountain. This peak has been very recently uncovered, and is extremely rugged both in general form and in details. The rise of 1,000 feet on the western face is a precipice from top to bottom. If one fell from the edge he would pass entirely to the bottom. At the same time the lower areas of land in the vicinity of this peninsula are well rounded and smooth, as has been noted in other parts of the Greenland coast.

From this it may fairly be concluded that not only may we expect greater irregularity of form in the higher peaks than in the lower lands of a region that has been glaciated, but also that we have here in the Upper Nugsuak peninsula an excellent illustration of this. Views taken in various parts of this peninsula excel in ruggedness the peak which Professor Chamberlin pictures† as proof of nonglaciation, and yet upon its angular surface transported pebbles were found; also views of the same

* This is the Devil's Thumb as given on the Danish and British Admiralty charts. The real Devil's Thumb of the Arctic explorers is some 40 or 50 miles to the north of this.

† Bull. Geol. Soc. Am., vol. vi, 1894, p. 219; see also Salisbury: Jour. Geology, vol. iv, 1896, p. 773.

THE DEVIL'S THUMB

Elevation 2,650 feet; glaciated surface in foreground; rugged, angular topography in background on left. Transported pebbles obtained on crest of the Devil's Thumb. Photograph by J. O. Martin

FIGURE 1.—RUGGED TOPOGRAPHY, UPPER NUGSUAK PENINSULA

Uplands glaciated. Mountain peak 2,000 feet above base. View taken from elevation of over 1,200 feet. Shows also an excellent overturned fold. Photograph by J. O. Martin.

FIGURE 2.—ABANDONED MORAINE (mapped in figure 1, page 262)

RUGGED TOPOGRAPHY AND ABANDONED MORAINE

hill, taken from the sea and from the land, will furnish as good a contrast between rugged and glaciated topography as do the two contrasted views which Chamberlin published.* Not only do these glaciated hills present an angular topography when viewed from a distance, but there is also ruggedness of detail (see plate 27, figure 1). Some of this is due to postglacial weathering and erosion, which in these high latitudes is extremely active, but most of it is irregularity inherited from preglacial times, because the scouring action of the ice has not been sufficient to erase even these minor preglacial details. There are minute ridges and valleys of this nature,† and in the depressions, which are true strike valleys, there are deposits of drift, proving preglacial origin for these irregularities. Rock basin lakes abound in these depressions, and one may pass entirely around their margin upon a rock wall. These seem to be depressions caused rather by preglacial decay than by glacial erosion. They are often so small and bounded by walls so angular that origin by ice scouring seems absolutely impossible. Not only is there this evidence of preglacial decay and slight erosion, but in places the rock is so deeply disintegrated that it is certainly the disintegration of preglacial times. This decayed rock, recently uncovered, is sometimes found near the ice in a place entirely too deep to have been caused in postglacial times, and yet the rocks near by are rounded by ice-scouring.‡ The ice-action has been unable to remove this decay product, but in the lower areas, where ice-currents have been more active and longer at work, no such decayed material was found.

The evidence of this rugged topography and failure to remove decayed rock from certain places that have been distinctly glaciated is of course proof of slight ice erosion. This slight erosion may be due either to the short time of action or to the unfavorable positions presented by the higher land, or to both. That it may well have resulted mainly from the topographic peculiarities, and notwithstanding long continued action, I am perfectly ready to believe, though not able to prove.§ A peninsula rising to a height varying from 1,000 to 2,500 feet and varying in width from two to four miles descends into a fiord valley whose depth below sealevel is fully 600 feet in places. The valley is deep and broad, the peninsula high and narrow. Even with long continued ice action it can hardly be expected that the peaks of this region, rising well into the ice

* Bull. Geol. Soc. Am., 1894, vol. vi, fig. 15, opposite p. 219.

† Exactly this same feature was found in Baffinland, a region of similar though less differentiated topography, which has also been subjected to general glaciation.

‡ In one case the decayed rock still preserved glacial striæ, and the ice had left it so recently that lichens had not begun to cover it.

§ In this connection attention may be called to the fact that there are areas of preglacially decayed rock in New England.

and distinctly above the currents caused by the topographic irregularities, would be extensively worn.

Extension of the Ice over the Upper Nugsuak Peninsula.

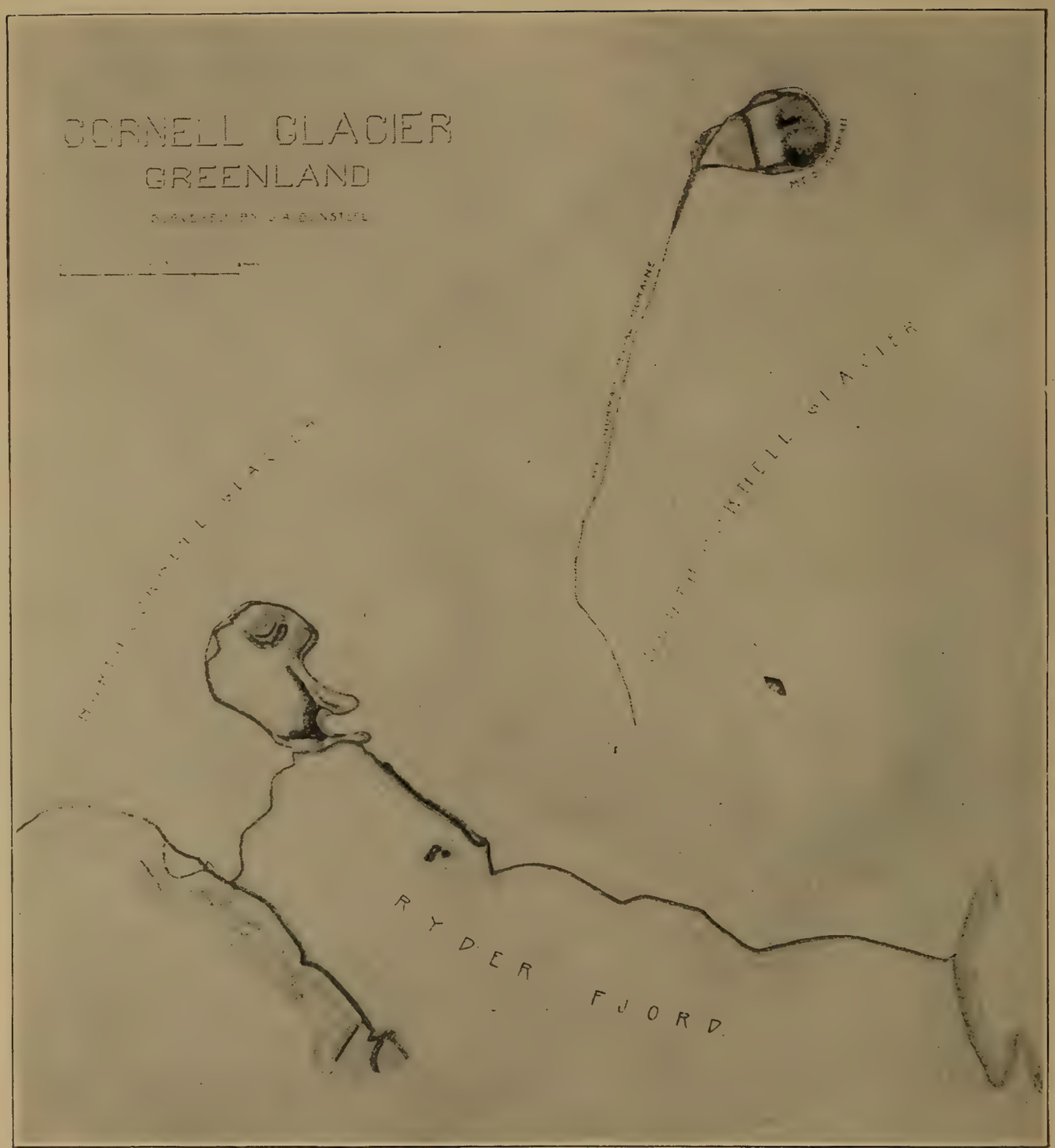
TOPOGRAPHY OF THE UPPER NUGSUAK.

This peninsula, which was made the base of our studies, is the longest arm of the land extending from this part of the Greenland coast. It stretches about southwest from the general coastline, and hence is not quite normal to its average course, which in this region is about north 15 to 20 degrees west (true north). From the ice-cap at the base to the extreme end of the Upper Nugsuak peninsula to Wilcox Head the distance is from 23 to 25 miles, and 8 or 10 miles farther, in the same line, are the Duck islands. Hence we have here a land area reaching to a distance of 30 or 35 miles from the present ice-margin The width of this land is nowhere more than 4 or 5 miles, and generally is only 2 or 3.

The elevation of the peninsula varies up to 2,900 feet, and there are many peaks reaching to heights between 1,000 and 2,500 feet. The topography is extremely rugged. It is evident that the narrow peninsula is a preglacial divide, and it is crossed by deep valleys, which often end in bays and fiords. These valleys extend across the peninsula, and in some cases have been perceptibly smoothed and grooved by glacial erosion. They have the appearance of mountainous valleys which have passed the stage of early youth, but were still young or adolescent when submergence transformed their mouths to fiords. This ruggedness of preglacial origin is increased by the effects of marked postglacial denudation. The hill tops and sides have been gullied by the mountain torrents, furnished with floods of water when the snow melts before the rising summer sun, and the valley sides and hill slopes have been encumbered with extensive talus accumulations of frost-riven boulders of great and small size. So rugged is the country from this cause that our average rate of progress over its surface on foot probably did not exceed one mile an hour.

The rocks are of metamorphic origin, and from a field study appear to have been derived from a sedimentary series. This has been intricately folded and faulted.* Among the rocks there is much variation in texture and in resistance to denudation, and hence the topography is often nearly related to the rock structure and position. This is especially well shown where trap dikes cross the metamorphic series, for their position is almost invariably marked by valleys. No sedimentary strata were

* The bed-rock geology was studied by Professor Gill, and he will publish his results after studying the thin-sections of rock.



CORNELL GLACIER, GREENLAND

found in place, and no other igneous rock than diabase. After the careful study made by Professor Gill and the diligent search of all the other members of the party, it is safe to say that no rocks other than trap, schist, and gneiss occur in place on the Upper Nugsuak peninsula.

On either side the peninsula is bounded by the waters of the fiords. Here and there islands rise above their surface, and in them there are occasional shoals. No soundings were made, but from the larger icebergs that float in the water and from the high ice-front of the glaciers that terminate in them, breaking off to form large bergs, it is evident that the water is deep in some places, and probably very often not less than 500 or 600 feet in depth. Between the Duck islands and Wilcox Head immense icebergs were constantly floating, though about half way between these two places bergs rising nearly 100 feet above the water were aground. A sounding made in this vicinity, at a distance of about two miles from Wilcox Head, in the direction of the Duck islands, showed the depth to be 114 fathoms. From an estimate of the height of the bergs which float though these waters, we had predicted the depth to be not less than 100 fathoms.

CORNELL GLACIER.

On the south side of the Upper Nugsuak peninsula there is a large glacier terminating in the fiord, to which the name Cornell glacier is given, and on the north side, ending in the Devil's Thumb bay, is another large glacier named the Wyckoff glacier.*

The latter was not studied in detail, nor was it mapped. Even late in August the sea ice had not yet disappeared from the foot of this glacier, and this fact, taken in connection with the scarcity of icebegs in the Devil's Thumb bay, showed that this glacier is not advancing rapidly. The southern boundary, separating it from the Cornell glacier, is a series of low but long nunataks, extending in the direction of the strike of the rocks. The outermost of these is fully 15 miles from the ice-margin.

The Cornell glacier (see plate 28) is a double one, divided near the coast by a partial nunatak named mount Hope. The southern arm is about $4\frac{3}{5}$ miles long, the northern about $1\frac{2}{5}$ miles. The sea-front is an ice-wall of remarkable whiteness and the surface is marvelously rough. Because of this roughness it seemed impracticable to obtain the rate of motion of the glacier, but from the small amount of ice coming from the front, the movement is evidently not very rapid. The land margin presents many features of interest, including distinct moraines. About 8 miles from the margin rises mount Schurman,† a nunatak reaching 1,000 feet above the ice on the western side. From this there extends a partial

* After Mr E. G. Wyckoff, whose liberality made the expedition possible.

† Named for President J. G. Schurman of Cornell University.

moraine stretching seaward, the sole blotch upon the otherwise universally white surface. Here and there the ice rises in the form of mounds several hundred yards in diameter and cracked upon the surface. These appear to mark the site of hills now buried beneath the ice, but near enough to the surface to produce an irregularity. To the westward of mount Schurman there is a mound of this sort, showing an elevated crevassed ice-surface when seen from the east, but proving the existence of the peak by the presence of land, which may be seen from the west or water side. This is a nunatak which is just now beginning to appear (see plate 28).

At present the Cornell glacier comes to the land at the base of the Upper Nugsuak peninsula, presenting either a steep slope or else a precipitous wall of ice, which is usually faced by a moraine embankment. West of it rises the land of the peninsula to the height of 1,000 or 2,000 feet above its present marginal surface. Turned to the northwestward and southwestward by this highland ridge, the ice creeps into the valleys forming the Wyckoff and Cornell glaciers; hence along this margin the ice movement is diagonal to that of the main ice-cap and the valley glacier tongues.

The moraine that is built along this land margin is made of very bouldery boulder-clay. The rock fragments are mainly gneiss, but in the moraine are found numerous pebbles and large boulders of a porphyritic red granite, of slate, and of quartzite. Somewhere to the eastward of the margin of the ice there must be a source for these materials, and it is mainly from a study of their distribution that the former glaciation of the peninsula was determined.

EVIDENCES OF FORMER ICE INVASION.

From the topography, excepting that of the lower zones, we obtained no help in our effort to determine the former extent of the ice-sheet. The ruggedness of the hills was such that from the topography alone no one would infer glaciation. Oftentimes, when viewed from the ice-cap or from the eastern base of the peninsula, the surface of the highlands can be seen to be distinctly smoothed; but the highest parts of the land invariably present a rather angular surface when viewed from the seaward or western side. As has been said above, this applies also to minor details; and decayed rock, evidently preglacial in origin, was found in several places.

In the highland portions of the peninsula the weathering has been so effective that the glacial striæ have been removed from the bed rock; but near sealevel, where the ice staid for the longest time, and from which it has only recently withdrawn, glacial striæ were found in numerous

places. The same is true of till deposits. They were never found on high, steep hillsides, but were seen at several places in the lower parts of the peninsula, as well as in the lower valleys of moderate slope. A rather extensive boulder clay bed exists on the northwestern side of Wilcox Head, where it has evidently been brought from the highlands and accumulated on the northwestern or lee side of the hill. Near the top of Wilcox Head, also on the lee side of the ridge, upon a moderately steep upland, a bed of boulder-clay was found at an elevation of 1,200 feet above the sea.

Having determined the nature of the bed rock exposed, we were easily able to trace the former glaciation by means of the distinctly unusual transported pebbles and boulders of red porphyritic granite, slate, and quartzite.

The nunatak mount Schurman rises above the surface of the ice of Cornell glacier 460 feet on the eastern side, and on the western 1,000 feet above the surface of the ice. Upon the very top of this mountain transported pebbles were found, and one slate pebble with perfectly preserved glacial striæ on the under side was brought away.

Mount Hope, reaching 1,450 feet above the sea and 390 feet above the base of the ice on the eastern side, has also been glaciated over its entire area, but it has a broad, well rounded surface.

The Devil's Thumb (as marked on the Danish and British Admiralty maps, though incorrectly), rising 2,650 feet above the sea, at a distance of about five miles from the ice, has transported blocks upon its crest. A specimen of scratched slate was brought from here.* At numerous high points on the peninsula transported fragments were found, and all proof that we could obtain pointed toward the conclusion that every bit of land of this peninsula had been glaciated.

On Wilcox Head, in addition to the boulder-clay bed at an elevation of 1,200 feet, mentioned above, transported blocks of quartzite and red granite were found at an elevation of 1,400 feet above the sea 25 miles to the westward of the present ice margin. At the Duck islands, 8 or 10 miles from Wilcox Head, in addition to the bed of boulder-clay mentioned, numerous pebbles of quartz and red granite were found, and it was shown that the surface of this, the outermost land of this portion of the Greenland coast, had also been glaciated.

Amount of former Ice Invasion.

This is proof that the ice in this portion of the Greenland ice-sheet reached at least 30 or 35 miles to the westward. That is as far as there

* Obtained for me by Professor Gill and Mr Martin.

is opportunity to find proof. At the Devil's Thumb, 5 miles from the present margin, the glacier overrode an elevation of 2,650 feet above sea-level, and hence at this point had a thickness of certainly not less than 3,000 feet, for the depth of the fiord must be added to the mountain height, and then a certain amount must be added to the thickness in order that the ice might move and carry fragments to the top. I believe that at this place the depth of the glacier could not have been less than 4,000 feet, for there is such a steep grade from the present margin to the tip of the Devil's Thumb that to have moved up this and reached the tip, carrying fragments of slate derived from some point within the ice boundary, could hardly have been done by a glacier which merely veneered the mountain's surface. There must have been distinct movement, and that this was so is proved by the fact that, although extremely rocky and angular on the sea or western face, the back or eastern side of the Devil's Thumb shows distinct topographic signs of ice scouring. Even granting no more than 3,000 feet, which must be admitted, the ice-sheet here was a thick one.

Nearly the same amount of thickness must also be admitted for the end of the peninsula, where transported fragments were found at an elevation of 1,400 feet, while the fiord near it has a depth estimated to be 100 fathoms upon the basis of the size of the icebergs that float in its waters. A depth of 114 fathoms was found within 2 or 3 miles of this place, off the western side of Wilcox Head, in the direction of the Duck islands. Here, then, in the immediate neighborhood of Wilcox Head, the ice-sheet could not have been less than 2,000 feet in depth, and in all probability was deeper than this. At the Duck islands, adding their elevation of 100 feet to the water depth of at least 600 feet, it is necessary to believe that an ice-sheet existed at this point, from 30 to 35 miles distant from the present glacier margin, with a depth of not less than 700 feet and probably much more.

Therefore the evidence on this part of the Greenland coast is that the glacier of Greenland extended beyond the limit of the outermost land, carrying materials whose place of origin is within the present ice-boundary. In the places studied by various parties on the American side of these waters it is found that ice has also covered this land. Our party found that ice had covered the highest hills in Cumberland sound, on Baffinland, and had reached out toward the sea into the waters which separate Greenland and Baffinland.

From the evidence at hand, no one is warranted in assuming the junction of these two ice-sheets; but, on the other hand, it cannot now be denied as a possibility. On the two sides of a sea 300 or 400 miles

wide the ice-sheet has recently extended beyond the outermost limit of the land. Where did it stop?

Recent Advance.

In the moraine near the sea end of the northern arm of Cornell glacier (north side) marine shells were found at an elevation of 50 feet above the sea and in such a position that they must have been brought there by the ice. The shells are of species now living in the fiord, and include *Saxicava*, *Mya*, etcetera. That they were not brought there by animals is proved by their abundance, and moreover by the fact that they were found embedded in the boulder clay of the moraine. This point also proves that they were not accumulated here by a change in land level. Whatever their sources, they were brought to these places by the same cause that built the moraine, and this is known to be the ice.

Mr E. M. Kindle later studied these is some detail and searched for them elsewhere. He was successful in finding them at an elevation of 586 feet above sealevel, at a distance of from 4 to 5 miles from the sea; and not only did he find them in the moraine, but also *in the ice itself*. Some were whole, but most of the specimens were fragments.

These observations confirm the conclusion that the ice is now advancing over an old seabottom at a distance of several miles from the present margin. Whether this means that the glacier is now removing fossiliferous preglacial beds, or whether some recent retreat has caused the fiord to reach some miles further inland than now, cannot be definitely stated. The latter seems the more probable, because it is difficult to believe that during all the time during which the ice has occupied this fiord, scouring the rocks of its margin to a depth below the zone of decay and rounding them to *roches mountonnées* forms, there should have been any of the soft-beds of the seabottom left. This of course is possible, but a slight retreat would equally and more naturally account for the phenomena.

There is apparently less energy of movement in the Cornell glacier than in glaciers in some other parts of the Greenland coast. It is possible that there is some topographic cause for this. If, for instance, the head of the fiord at the present margin of the glacier is not far from the divide, a very slight change in the supply may make a marked difference in the rate of advance of the glacier, so that even with slight variations in ice supply there may be marked changes in the glacier front. That there is some such topographic peculiarity as this is indicated by the surface of the glacier, which is elevated into numerous domes, evidently where hill-tops lie buried beneath it. At present these are overridden; soon this

may be more difficult, and then, with the supply nearly cut off, the front will rapidly draw back. With a slight increase in supply again the hill may once more be buried by the ice and the front of the glacier can advance to its old position.

Present Boundary of Cornell Glacier.

It is not my purpose to speak here in detail concerning the many interesting features observed at the boundary of the Cornell glacier. This boundary was followed for many miles, and the ice-face and moraine-

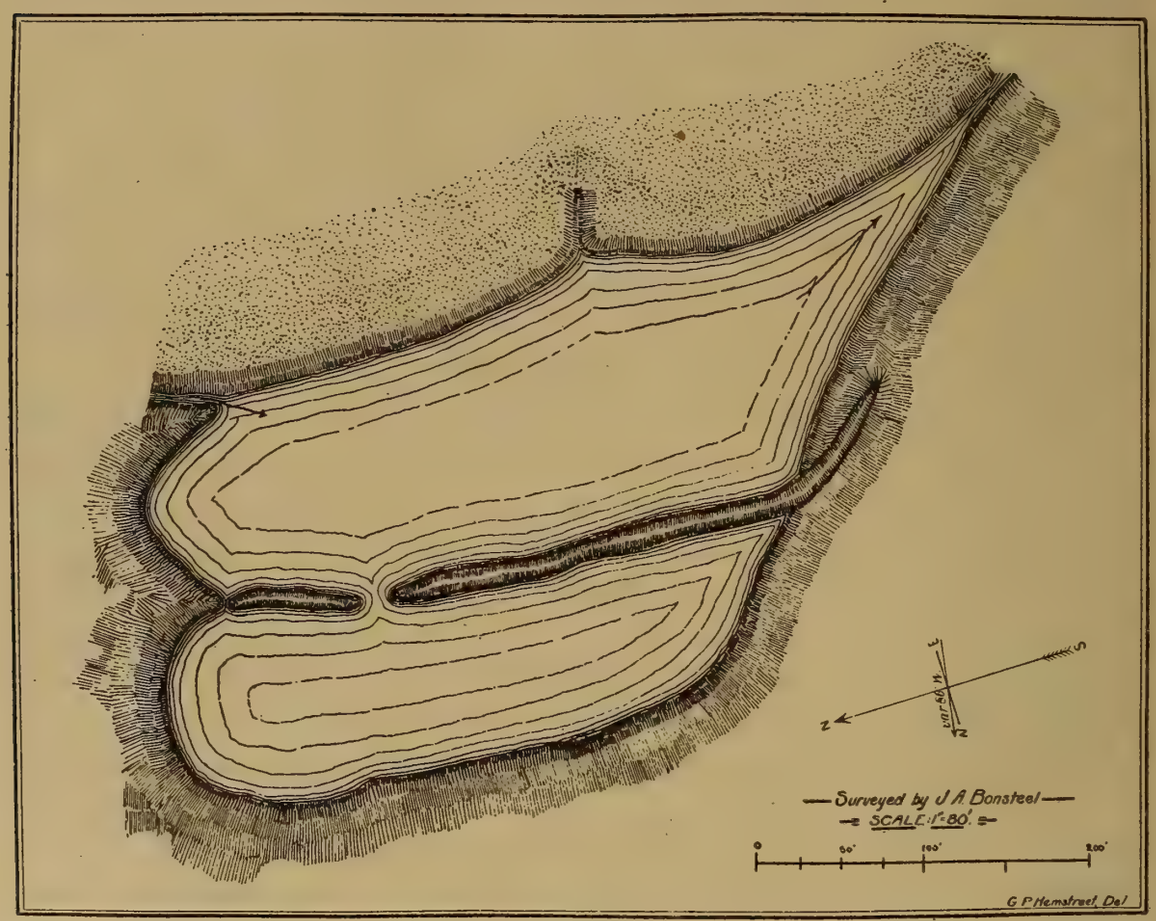


Figure 1.—*Marginal Lake near End of North Cornell Glacier.*

Showing position of abandoned moraine. Ice dotted.

foot studied. It was soon recognized that the front of this glacier was even now in process of change, and realizing the importance of leaving some record, by means of which at some future time the amount of change might possibly be determined, I selected the places that appeared to be the ones which promised to most delicately register changes of position. For this purpose the northern arm of the Cornell glacier was

chosen. Numerous photographs were taken* to show the ice-front in various places, and several records were left from which the position of the present front was determined. These records are described in some detail below.

The first record is on the northern side of the north arm of Cornell glacier, about a quarter of a mile from the sea. Here a survey was made (August 18, 1896) of the ice-margin, an ice-dammed lake, and some moraine embankments of boulder-clay (plate 27, figure 2), left by the retreating glacier, the present margin of which was also determined (figure 1 of the text). The survey was made from a short baseline at an elevation of 60 to 100 feet above sealevel, in the amphitheater which forms the most marked indentation in this part of the present boundary. Here the steeply rising walls of the peninsula retreated from the ice for several hundred yards, forming a turf covered amphitheater whose length is about a quarter of a mile. Between the headlands of this indentation a shallow marginal lake is now held by a moraine dam. The baseline was marked by cairns at each end, and at the base of each of these a record was placed. The map made from this survey is reproduced as figure 1.

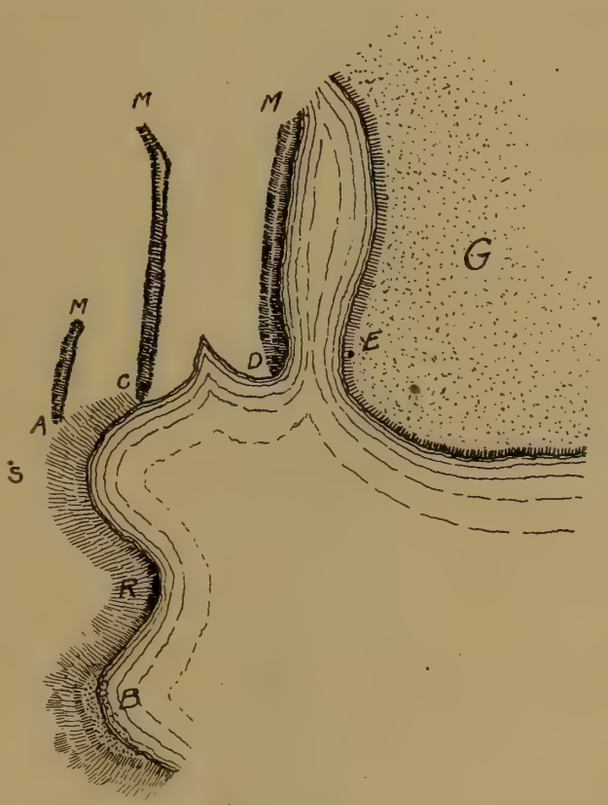


FIGURE 2.—*Northern End of Sea-front of Cornell Glacier.*

B, Boulder beach; *R*, Rock point; *G*, Glacier; *S*, Transit station and cairn; *M*, Moraine embankments. Distance from *A* to *C*, 133 feet; from *C* to *D*, 212 feet; from *D* to *E*, 110 feet.

Just below this place (toward the sea) the sea end of the glacier was marked (August 19, 1896) by a cairn left on the rock at a distance of about 40 feet from the sea and an elevation of 25 feet above it. From this the distance was measured by stadia readings to the nearest part of the ice-front, and also to the ends of the three moraines (more fully described below) marking stages in the present retreat of the ice. The location of this cairn and the position and distance of ice from it are approximately shown on the accompanying sketch (figure 2).

* Copies of these photographs will finally be added to the Geological Society of America series and the negatives placed among the collections at Cornell University.

The third cairn was built at the junction of the north Cornell glacier and the nunatak, mount Hope, just above the level of the sea (plate 29). Here a distinct T was cut in the rock (August 19, 1896) and covered by a large stone, which was protected by a cairn. This was placed three feet from the present ice-front, almost exactly where the glacier impinges upon the rock. Any advance of the ice will overturn the cairn and possibly obliterate the T. If the present retreat continues the cairn may be expected to remain.*

The final place to which attention may be especially called is the southern face of this nunatak. Mount Hope itself rises steeply above the sea, but it extends southward as a low ice-capped elevation. In the southernmost parts it is a mere cliff, reaching about 700 feet above the sea and capped by the ice, which reaches nearly to the margin. A tongue of south Cornell glacier extends northwardly behind this low hill, protrudes as a valley glacier tongue, and terminates in a lake. There is a photograph of the end of this glacier, and any future change in its outline can be easily determined by comparison with this. The main south Cornell glacier enters the sea on the south end of the low hill. In one place the cap of ice, which reaches to the tip of this hill and presents a low cliff toward the fiord, climbs over the cliff and passes down a low valley to the sea. Even a very slight change in the supply of ice must produce a very notable difference in the form of this delicately balanced tongue of the glacier. The photograph reproduced as plate 29 shows clearly the position and form of this. If this glacier is visited in the future, from these facts we may obtain a record of the movement in the interval.

Recent Retreat of Cornell Glacier.

There seems to be evidence that the Cornell glacier has been progressively withdrawing, and at present its front is certainly moving backward. One of the reasons for the greater ruggedness of the high peaks is no doubt longer exposure to postglacial weathering. The marked difference in freshness of the rounded rock surfaces in low and moderate elevations is proof of this. There is also evidence that the ice has occupied the lowland near the head of the fiord more recently than the parts farther out toward Baffin bay. Glacial striæ and fresh *roches moutonnées* surfaces abound near the present ice-margin, but they become much less marked and noticeable half way out toward the end of the peninsula.

* The place occupied by this cairn is just south of the high portion of the nunatak and on the south side of a narrow valley, now dammed by the ice and occupied by a lake.

FACE OF A PART OF NORTH CORNELL GLACIER

Showing mount Hope in the middle, with an ice-tongue hanging over the cliff and just reaching the sea. Mount Schurman is on the extreme right. View taken from height of 1,200 feet. Photograph by J. O. Martin.

In some of the inland valleys of the Upper Nugsuak, and particularly on the northern side of the peninsula, small glaciers even now exist, and one of them reaches to the sea.* From this latter glacier there is every gradation down to those that are hardly more than snowbanks, and in some places one is in doubt whether to call them mere banks of snow or glaciers. These are disappearing and represent the last stage in the withdrawal of the ice-sheet. That this is so is proved by two facts. Below some of the snowbanks striæ are found, showing that they once gathered and transported materials; also near the small valley glaciers, and especially near the one which reaches the sea, there are fresh striæ and bare rock surfaces not now covered by lichens and with the boulders fresh and unaltered. Not only is this true, but in several of the inner valleys there are striæ showing former but very recent glacial action where now no glaciers exist. The last phase of the ice occupancy of the Upper Nugsuak was that of the valley glaciers, at first extensive, now shrunken and almost destroyed. Probably this withdrawal is still in progress; certainly it has recently been.

Evidence of recent general retreat is also found on mount Schurman. Upon this peak, rising as it did above the zone of most rapid ice erosion into the clear middle layers of the glacial ice, there is little sign of glaciation. Its topography is rugged, and by postglacial weathering the striæ have been removed from the bed rock. However, even a small slate pebble has perfectly preserved scratches on the under side where it rested on the ground. It was not embedded at all, but merely laid on the surface, and so was partly protected from the air.

In addition to this evidence that the ice recently overrode the peak, the flora furnishes collateral proof. From the Duck islands up to the very ice margin, even to the nearly surrounded nunatak, mount Hope, the flora is well developed, and there is a great variety of lichens and mosses and great abundance of grasses and various flowering plants; but on mount Schurman, separated from this land by about 7 or 8 miles of ice, the flora is very different. Mosses, lichens, and some grasses are as abundant as at the end of the peninsula, but flowering plants are rare, excepting in the case of certain species which have light seeds. In other words, the light seeded plants, which can be distributed by the wind, have had time to reach the nunatak and take possession of it since the ice left; but the heavy seeded flowering plants have not found time to take a place on the mountain.

That these conditions of plant distribution are not due to any climatic features is apparent to any one who knows under what adverse condi-

* See Tarr: Am. Geologist, vol. xix, April, 1897.

tions these Arctic plants thrive. Given a place to grow and a seed properly placed, the plant will develop and mature its seed in the short summer season. Moreover, even on the higher parts of this nunatak there are some individuals and colonies of the heavy seeded flowering plants; but these are scattered and are evidently spreading from centers. Wherever one is found there are generally others near by, but of some species only one colony was found on the entire mountain. The agents of distribution are the ptarmigan and snow-bunting, which could be seen flying about on the mountain side. The work of plant distribution has just reached this stage, and it is quite certain that there has not been a great lapse of time during which the land has been open to this distribution.*

Evidence of present Retreat of Cornell Glacier.

Evidence of recent retreat was found all along the ice-front. The valley glacier tongue of mount Hope (described above, page 264) has a fresh moraine fully 100 feet from its terminus. On the margin of this mountain a moraine is found at a considerable distance from the present edge of the main ice-sheet. In the same region a marginal lake has been able to change its place of outflow, thus lowering its level as a result of the retreat of the ice-edge. The old recently abandoned channel is distinctly seen; and that within a very short time it served to discharge the lake waters is proved by the fact that lichens have not yet begun to grow on the rock in the bed of the channel nor on the rock shores of the present lake below the old level.

On the moraine along the northern side of the north arm of the Cornell glacier we find the same evidence. The moraine embankment stands at a distance of 50 or 100 feet from the present edge of the ice, and it is not a part of the glacier, but distinctly separated from it as a true moraine, not debris-covered ice. This is frequently proved by the fact that the valley occupied by the stream which separates the moraine ridge from the ice, has cut down to the very base of the glacier. So recently have these moraine embankments been abandoned by the glacier that no vegetation exists upon them, neither lichens on the pebbles nor grasses in the clayey soil. In one place, at a distance of 35 feet beyond such a moraine and still farther from the ice, the bed-rock was found to be polished and scratched, and this so recently done that no lichens existed upon it. It is necessary to go 40 feet farther than this to find thoroughly lichen-covered rocks. Therefore at this place the lichens are following

*A botanical study of the nunatak flora would be of extreme interest.

the retreating glacier, and in some places have reached no nearer than 140 feet from its present edge.

Along the same margin, near the ice-front, there are three parallel moraine ridges (figure 2, page 263), the outermost being about 150 yards from the glacier margin, and situated upon the hillside. It is not bouldery, and hence is rapidly disappearing under the attacks of the weather. The second ridge is very long and sinuous, being quite like an esker in form. It extends a distance of half a mile parallel to the ice-margin and about 200 feet from it on the average. In its course it passes through the middle of the marginal lake (figure 1, page 262).

The moraine which lies nearest the glacier is just now being abandoned. In some places it is connected with the glacier, and everywhere is partly underlaid by ice. Since this is melting, the surface of the ridge is very muddy and irregular, because of the breaking down of the mound as the ice melts beneath. In some places it is entirely disconnected from the glacier. There is no vegetation on this moraine. On the middle ridge there is one species of grass, found in a few patches, and some lichens are growing on the pebbles. On the outermost moraine there are several species of plants. Beyond this there are other more indefinite ridges, evidently marking still earlier halts; but these are so ancient that they are entirely covered by vegetation.

Summary of Conclusions.

The observations presented in this paper seem to warrant the following conclusions:

It is evident that rugged, angular topography does not necessarily indicate freedom from ice invasion. A rugged peak rising into the ice might for a long time retain its angularity. Such peaks are naturally more angular, both because of longer exposure to pre and post-glacial denudation, and also to the greater activity of denudation in the higher altitudes. Notwithstanding angular topography, the Upper Nugsuak peninsula has all been glaciated, and the ice-sheet has extended beyond the limits of the outermost land, the Duck islands, which lie 30 or 35 miles from the present ice-front.

There is no evidence which points to any particular limit of the ice advance, and, for all we can prove by distinct observations in this place, the glacier at one time may have joined the Baffinland ice-sheet. The glacier has recently withdrawn and is even now in process of retreat. However, the discovery of fossils and recent shells on the moraine and

in the ice apparently proves that there has been a recent advance, preceding the present retreat. This former variation is not necessarily great in amount. There are no evidences to show the exact amount.

At present the ice is receding at a rate which promises to be measurable after a few years have elapsed. In order to make such measurement possible, records were left by the Cornell party at places which may easily be found.